

INSTRUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. AD-A215 842			1b. RESTRICTIVE MARKINGS	
2a.			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE				
4. PERFORMING ORGANIZATION REPORT NUMBER(S) UBUFFALO/DC/89/TR-120			5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION Depts. Chemistry & Physics State University of New York		6b. OFFICE SYMBOL (If applicable)		7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Fronczak Hall, Amherst Campus Buffalo, New York 14260		7b. ADDRESS (City, State, and ZIP Code) Chemistry Program 800 N. Quincy Street Arlington, Virginia 22217		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Office of Naval Research		8b. OFFICE SYMBOL (If applicable)		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Contract N00014-86-K-0043
8c. ADDRESS (City, State, and ZIP Code) Chemistry Program 800 N. Quincy Street Arlington, Virginia 22217		10. SOURCE OF FUNDING NUMBERS		
		PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO. WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) Chemistry at Clusters, Microstructures and Surfaces				
12. PERSONAL AUTHOR(S)				
13a. TYPE OF REPORT Final		13b. TIME COVERED FROM 12/1/85 TO 11/30/89		14. DATE OF REPORT (Year, Month, Day) December 1989
15. PAGE COUNT 19				
16. SUPPLEMENTARY NOTATION				
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	CLUSTERS SPECTROSCOPY MICROSTRUCTURES DYNAMICS SURFACES ELECTRONIC STRUCTURE	
19. ABSTRACT (Continue on reverse if necessary and identify by block number) <p>The objective has been to develop theoretical models and computational codes to describe chemical and physical phenomena associated with clusters, microstructures and surfaces, in order to gain a better understanding of surface/solid-state chemistry and its role in applied areas such as catalysis and microelectronics. The approach has been to examine topics relevant to this objective, using techniques appropriate for molecular dynamics, spectroscopy and electronic structure. The following nine topics have been studied: (1) clusters, with emphasis on geometry, stability, spectroscopy and reactions; (2) infrared-laser-excited adspecies with emphasis on energy and phase relaxation and desorption; (3) ultraviolet-laser-induced chemical vapor deposition; (4) resonance fluorescence at flat metallic surfaces; (5) photochemistry at structured metallic surfaces, with emphasis on gratings and thin films; (6) phase-conjugated surfaces; (7) laser-induced reactions in solid matrices; (8) nonlinear optical processes in polymeric systems; and (9) molecular dynamics simulations.</p>				
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. David L. Nelson			22b. TELEPHONE (Include Area Code) (202) 696-4410	22c. OFFICE SYMBOL

Final Report

Submitted in

December 1989

to the

Chemistry Program Office

of the

Office of Naval Research

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

Title of Report: Chemistry at Clusters, Microstructures and Surfaces

Contract Number: N00014-86-K-0043

Principal Investigator: Thomas F. George

Institution: State University of New York at Buffalo
Buffalo, New York 14260

Amount of Funding: \$390,000

Duration: 1 December 1985 to 30 November 1989

CONTENTS

	<u>Page #</u>
Summary	3
Research Personnel.	7
Publications.	8
Conference Abstracts.	17

Summary

The objective under the current ONR contract has been to develop theoretical models and computational codes to describe chemical and physical phenomena associated with clusters, microstructures and surfaces, in order to gain a better understanding of surface/solid-state chemistry and its role in applied areas such as catalysis and microelectronics. The approach has been to examine topics relevant to the above objective, using theoretical techniques appropriate for molecular dynamics, spectroscopy and electronic structure. Various topics are listed below, with one or two sentences describing a representative accomplishment and/or result for each topic.

I. Clusters

A. Geometry and Stability

- Extended Hückel molecular orbital calculations along with graph theory have been used to determine relative stabilities and geometries of alkali metal clusters (neutrals, cations and anions) for sizes up to fourteen atoms, and an analysis has been made with respect to trends in orbital energies, shell structures, ionization potentials and extrapolation to the bulk limit.
- A non-Cartesian coordinate system has been developed which permits the vibrational motions of Buckminsterfullerene (C_{60}) to be expressed in terms of four force constants, where a 180×180 matrix is diagonalized to yield the complete vibrational spectrum.

B. Spectroscopy

A comprehensive treatment of classical decay rates for a molecule in the vicinity of a spherical metallic surface has been carried out, where results have been obtained for both radiative and nonradiative transfer when the molecule is located outside or inside the surface.

C. Reactions

Using a tight-binding calculation to determine the geometry and charge distribution of Si_n^+ for n ranging from 30 to 45, a hypothesis has been verified that large silicon clusters are arranged in a cylindrical shape as stacked quasigraphite rings, which seems to explain the experimental observation of periodic variations in reactivity of Si_n with NH_3 and CH_3OH as n is varied.

II. Infrared-Laser-Excited Adspecies

A. Energy and Phase Relaxation

- The Born and Markov approximations for phonon relaxation and coherent excitation of adsorbed species have been shown to be invalid for CO adsorbed on Ni or Cu (a strongly-bound physisorbed system) but valid for the weakly-bound system of Ar on W.
- A master equation approach which includes electron-hole excitations in the substrate reveals that the probability of finding a laser-driven adsorbed CO molecule on a Cu surface in its first excited vibrational state is 0.03, which is encouraging for experiments on laser-stimulated surface reactions involving CO.
- The vibrational dephasing rate for OH on SiO_2 has been found to be considerably faster than the energy relaxation rate, and the calculated value of 4 ps for the dephasing relaxation time (corresponding to a linewidth of 1.3 cm^{-1}) is in good agreement with experiments.

B. Desorption

A master equation approach shows that a pulsed laser does not lead to a dramatic increase in the rate of desorption, and in the high-intensity limit, resonant heating and desorption reach the same saturation limit for a pulsed laser and for a continuous-wave laser.

III. Ultraviolet-Laser-Induced Chemical Vapor Deposition

Using the Rayleigh hypothesis and determining all components of the electromagnetic field (incident laser, reflected field, image field and surface plasmon field), the dynamics of periodic structured growth of Cd on Si, resulting from photolysis of gaseous $\text{Cd}(\text{CH}_3)_2$, has been calculated in order to explain experimental results.

IV. Resonance Fluorescence at Flat Surfaces

A rigorous quantum theory of atomic resonance fluorescence near a flat metallic surface has been derived which allows for polarization-dependent detection involving specific transitions between degenerate substrates.

V. Photochemistry at Structured Surfaces

A. Gratings

The photodissociation of I_2 above a Ag grating surface has been calculated semiclassically, where there is an optimal distance of the molecule from the surface at which dissociation is a maximum. The reason for this is that the enhancement due to the surface plasmon field as the molecule is brought closer to the surface is offset by a diminution due to line-broadening effects.

B. Thin Films

Due to cross-coupling into long- and short-range surface plasmons and the different coupling nature between radiations from an incident laser and from the molecular dipole to a corrugated thin metallic film substrate, it has been shown that enhanced photoabsorption may be achieved through control of the various film parameters.

VI. Phase-Conjugated Surfaces

An atom near a phase conjugator behaves quite differently than an atom in empty space or in the vicinity of an ordinary (linear) surface, and it is shown with nonlinear optics that an atom in its ground state can fluoresce if it is sufficiently close to a phase conjugator. This

phenomenon opens the door to new and novel types of surface spectroscopy.

VII. Laser-Induced Reactions in Solid Matrices

To describe recent experiments on laser-induced chemical reactions in HCl- and Cl₂-doped xenon solid, a semiempirical approach called the diatomics-in-ionic systems (DIIS) method has been developed which accounts for the coupling between ionic and neutral species and charge delocalization among host rare-gas atoms. Calculations have been carried out by treating 66 Xe matrix atoms via pairwise interactions, including polarization, with the remaining part of the matrix treated as a continuum, and it has been shown that the positive charge in the ionic activated complex is distributed most often between several Xe atoms forming, in general, a Xe₁₂⁺Cl⁻ molecule. A theoretical prediction of the excitation spectrum of Xe₁₂Cl has been confirmed experimentally (after annealing, such that Cl is at a substitutional site).

VIII. Nonlinear Optical Process in Polymeric Systems

The transient behavior of the nonlinear optical susceptibility of polydiacetylene induced by an ultrafast pump field is investigated. Spectral hole burning, optical nutation and optical bistability are observed theoretically.

IX. Molecular Dynamics Simulations

A semiclassical wavepacket method has been developed for studying the dynamics of various nonequilibrium statistical processes in condensed phases. The development is based on the construction of a Gaussian density matrix satisfying the maximum entropy principle.

Research Personnel

<u>Name</u>	<u>Current Affiliation</u>
Dr. Henk F. Arnoldus	Villanova University
Mr. Reimin Chen	State University of New York at Buffalo
Dr. Thomas F. George	State University of New York at Buffalo
Dr. Daniel A. Jelski	State University of New York, College at Fredonia
Dr. Andy Langner	Rochester Institute of Technology
Dr. Hyeong R. Lee	State University of New York at Buffalo
Dr. Peter Leung	Portland State University
Dr. Devaraj Sahu	Computer Sciences Corporation, Maryland
Dr. Sander van Smaalen	University of Groningen, The Netherlands

Publications

Each manuscript listed below corresponds by number to the Technical Report previously submitted to the Office of Naval Research for Contract N00014-86-K-0043. The major portion of these are refereed journal articles, and the remainder are invited book chapters and conference proceedings.

1. D. Agassi and T. F. George, "Surface Plasmon Dispersion Relation and Local Field Enhancement Distribution for a Deep Sinusoidal Grating," *Surf. Sci.* 172, 230-56 (1986).
2. M. Hutchinson and T. F. George, "Vibrational Dephasing of Admolecules by Phonons," *Chem. Phys. Lett.* 124, 211-5 (1986).
3. H. W. Lee and T. F. George, "Analysis of Experimental Data for Neutralization of Low-Energy Ions at a Solid Surface," *Surf. Sci.* 172, 211-29 (1986).
4. X. Y. Huang, K. T. Lee and T. F. George, "Resonance Fluorescence of a Two-Level Atom Near a Rough Metal Surface," *J. Chem. Phys.* 85, 567-72 (1986).
5. X. Y. Huang and T. F. George, "Energy and Phase Relaxation in Laser-Induced Admolecular Processes," in Advances in Laser Sciences - I, ed. by W. C. Stwalley and M. Lapp, AIP Conf. Proc. 146, 748-9 (1986).
6. J. Lin, X. Y. Huang and T. F. George, "Transient Excitation of Anharmonic Adspecies by Pulsed Laser Radiation," in Advances in Laser Sciences - I, ed. by W. C. Stwalley and M. Lapp, AIP Conf. Proc. 146, 750-2 (1986).
7. D. Agassi and T. F. George, "Light Scattering from a Deep Metallic Grating," in Advances in Laser Sciences - I, ed. by W. C. Stwalley and M. Lapp, AIP Conf. Proc. 146, 734-8 (1986).
8. P. T. Leung and T. F. George, "Photodissociation of Molecules at Structured Metallic Surfaces," *J. Chem. Phys.* 85, 4729-33 (1986).
9. T. F. George, D. Jelski, X. Y. Huang and A. C. Beri, "Theory of Spectroscopy and Dynamics in Laser-Irradiated Adspecies-Surface Systems," in Interfaces Under Laser Irradiation, ed. by L. D. Laude, D. Bäuerle and M. Wautelet (Nijhoff, Dordrecht, The Netherlands) NATO ASI Series E: Applied Sciences 134, 165-83 (1987).
10. H. F. Arnoldus, S. van Smaalen and T. F. George, "Thermal Relaxation of Adsorbed Atoms in an Intense Laser Field," *Phys. Rev. B*, 34, 6902-11 (1986).

11. H. F. Arnoldus and T. F. George, "Multiplicative Stochastic Processes Involving the Time-Derivative of a Markov Process," *J. Math. Phys.* 28, 340-6 (1987).
12. H. F. Arnoldus and T. F. George, "Laser-Linewidth Effects on the Photon-Phonon Conversion Rate at a Gas-Solid Interface," *J. Opt. Soc. Am. B* 4, 195-200 (1987).
13. S. van Smaalen, A. Peremans, H. F. Arnoldus and T. F. George, "Dynamics of a Laser-Irradiated Adatom," *Spectrochim. Acta* 43A, 201-5 (1987).
14. F. Battaglia, Y. S. Kim and T. F. George, "Heat Capacities of Rare Gases Adsorbed on Graphite," *J. Phys. Chem.* 91, 414-7 (1987).
15. S. van Smaalen, H. F. Arnoldus and T. F. George, "Laser-Heating of a Transparent Crystal via Adsorbed Atoms," *Phys. Rev. B* 35, 1142-6 (1987).
16. S. van Smaalen and T. F. George, "Vibrational Excitation of an Adbond by a Short-Pulsed Laser," in *Advances in Laser Sciences - II*, ed. by M. Lapp, W. C. Stwalley and G. A. Kenney-Wallace, *AIP Conf. Proc.* 160, 493-5 (1987).
17. A. Peremans, J. Darville, J.-M. Gilles and T. F. George, "Infrared-Laser Excitation of the Internal Vibrational Mode of a Diatomic Molecule Adsorbed on a Metal Surface," *Phys. Rev. B* 35, 2690-9 (1987).
18. J. T. Lin, X. Y. Huang and T. F. George, "Theory of Laser-Induced Phenomena on Conventional and Phase-Conjugated Surfaces," *J. Opt. Soc. Am. B* 4, 219-27 (1987).
19. S. van Smaalen and T. F. George, "Theoretical Study of Pulsed-Laser-Induced Resonant Desorption," *Surf. Sci.* 183, 263-75 (1987).
20. D. A. Jelski and T. F. George, "Dynamics of Patterned Laser-Induced Chemical Vapor Deposition," *J. Appl. Phys.* 61, 2353-7 (1987).
21. Y. Wang, T. F. George, D. M. Lindsay and A. C. Borzi, "The Hückel Model for Small Metal Clusters. I. Geometry, Stability and Relationship to Graph Theory," *J. Chem. Phys.* 86, 3493-9 (1987).
22. D. M. Lindsay, Y. Wang and T. F. George, "The Hückel Model for Small Metal Clusters. II. Orbital Energies, Shell Structures, Ionization Potentials and Extrapolation to the Bulk Limit," *J. Chem. Phys.* 86, 3500-10 (1987).
23. H. F. Arnoldus, S. van Smaalen and T. F. George, "Interaction of an Adsorbed Atom with a Laser," in *Lasers, Molecules and Methods*, ed. by J. O. Hirschfelder, R. E. Wyatt and R. D. Coalson (Wiley, New York), *Adv. Chem. Phys.* 73, 679-713 (1989).
24. I. Last and T. F. George, "Interaction of Xe^+ and Cl^- Ions and Their Formed Molecules with a Xe Solid Matrix," *J. Chem. Phys.* 86, 3787-94 (1987).

25. P. T. Leung and T. F. George, "Surface Distortions of Asymmetric Line Profiles," Chem. Phys. Lett. 134, 375-8 (1987).
26. S. van Smaalen and T. F. George, "Determination of the Incommensurately Modulated Structure of α -Uranium Below 37 K," Phys. Rev. B 35, 7939-51 (1987).
27. H. F. Arnoldus and T. F. George, "Role of Coherences in the Relaxation of Adsorbates," Phys. Rev. B 35, 5955-63 (1987).
28. S. G. Chung and T. F. George, "Generalization of Levinson's Theorem to Particle-Matter Interactions," J. Math. Phys. 28, 1103-6 (1987).
29. H. F. Arnoldus, D. Jelski and T. F. George, "Confinement and Redistribution of Charges and Currents on a Surface by External Fields," J. Math. Phys. 28, 1069-74 (1987).
30. F. Battaglia and T. F. George, "A Pascal-Type Triangle for the Number of Topologically Distinct Many-Electron Feynman Graphs," J. Math. Chem. 2, 241-7 (1988).
31. D. A. Jelski and T. F. George, "The Plasmon Dispersion Relation on a Rough Surface: A Simple Approximation," J. Phys. Chem. 91, 3779-82 (1987).
32. P. T. Leung, T. F. George and Y. C. Lee, "Limit of the Image Theory for the Classical Decay Rates of Molecules at Surfaces," J. Chem. Phys. 86, 7227-9 (1987).
33. P. T. Leung, Z. C. Wu, D. A. Jelski and T. F. George, "Molecular Lifetimes in the Presence of Periodically Roughened Metallic Surfaces," Phys. Rev. B 36, 1475-9 (1987).
34. Z. C. Wu, D. A. Jelski and T. F. George, "Vibrational Motions of Buckminsterfullerene," Chem. Phys. Lett. 137, 291-4 (1987).
35. H. F. Arnoldus and T. F. George, "Non-Markovian Line Shapes of Physisorbed Atoms on a Crystal," Phys. Rev. B 36, 2987-95 (1987).
36. D. M. Lindsay, L. Chu, Y. Wang and T. F. George, "The Hückel Model for Small Metal Clusters. III. Anion Structures and HMO Electron Affinities," J. Chem. Phys. 87, 1685-9 (1987).
37. I. Last, Y. S. Kim and T. F. George, "Cooperative Optical Transitions in Impurity Centers Coupled via Host Atoms," Chem. Phys. Lett. 138, 225-30 (1987).
38. S. G. Chung and T. F. George, "Quantum Adsorption for an Inverse Quadratic Potential," J. Phys. Soc. Jpn. (Letters) 56, 1289-92 (1987).
39. H. F. Arnoldus and T. F. George, "Quantum Theory of Atomic Fluorescence Near a Metal Surface," J. Chem. Phys. 87, 4263-72 (1987).

40. H. F. Arnoldus, P. T. Leung and T. F. George, "Fluorescence at a Surface," *Kvantovaya Elektronika* (Moscow) 15, 1161-7 (1988) [English version: *Sov. J. Quantum Electron.* 18, 740-3 (1988)].
41. A. C. Beri and T. F. George, "Theory of Laser-Stimulated Surface Processes. III. Desorption Through Vibrational Excitation by an IR Laser," *J. Chem. Phys.* 87, 4147-53 (1987).
42. P. T. Leung and T. F. George, "Energy Transfer Theory for the Classical Decay Rates of Molecules at Rough Metallic Surfaces," *Phys. Rev. B* 36, 4664-71 (1987).
43. S. van Smaalen and T. F. George, "On the Born and Markov Approximations: Phonon Relaxation and Coherent Excitation of Adsorbed Molecules," *J. Chem. Phys.* 87, 5504-11 (1987).
44. H.-W. Lee, S. van Smaalen and T. F. George, "Theory of Laser-Pulse-Induced Molecular Dynamics: Gas-Phase Molecular Collisions and Adbond Dynamics," in Atomic and Molecular Processes with Short Intense Laser Pulses, ed. by A. D. Bandrauk (Plenum, New York), NATO ASI Series B: Physics 171, 87-100 (1988).
45. I. Last and T. F. George, "Semiempirical Study of Polyatomic Rare Gas Halides: Application to the Xe_nCl Systems," *J. Chem. Phys.* 87, 1183-92 (1987).
46. H. F. Arnoldus and T. F. George, "Correlation Functions in Finite Memory-Time Reservoir Theory," *J. Math. Phys.* 28, 2731-8 (1987).
47. A. Haque and T. F. George, "Semiclassical Molecular Dynamics of Wavepackets in One-Dimensional Phase Space," in Condensed Matter Theories, Vol. 3, ed. by J. S. Arponen, R. F. Bishop and M. Manninen (Plenum, London, 1988), pp. 115-30.
48. I. Last, T. F. George, M. E. Fajardo and V. A. Apkarian, "Potential Energy Surfaces and Transition Moments of Cl Atom in Xe Solid Matrix," *J. Chem. Phys.* 87, 5917-27 (1987).
49. S. van Smaalen and T. F. George, "Pure Dephasing of a Vibrational Adbond," *J. Chem. Phys.* 87, 7307-14 (1987).
50. P. T. Leung and T. F. George, "Dynamical Analysis of Molecular Decay at Spherical Surfaces," *J. Chem. Phys.* 87, 6722-4 (1987).
51. S. G. Chung and T. F. George, "Theory of Low-Temperature Adsorption," *Surf. Sci.* 194, 347-78 (1988).
52. K. H. Yeon, C. I. Um and T. F. George, "Coherent States for the Damped Harmonic Oscillator," *Phys. Rev. A* 36, 5287-91 (1987).
53. I. Last and T. F. George, "Light Absorption by an Atom Moving Inside a Spherical Box," *Chem. Phys. Lett.* 142, 19-24 (1987).

54. H. F. Arnoldus and T. F. George, "Spontaneous Decay and Atomic Fluorescence Near a Metal Surface or an Absorbing Dielectric," *Phys. Rev. A* 37, 761-9 (1988).
55. Y. S. Kim, P. T. Leung and T. F. George, "Classical Decay Rates for Molecules in the Presence of a Spherical Surface: A Complete Treatment," *Surf. Sci.* 195, 1-14 (1988).
56. H. F. Arnoldus and T. F. George, "Correlations Between Photons in Resonance Fluorescence Emitted by an Atom Near a Metal Surface," *Phys. Rev. A* 37, 770-9 (1988).
57. H. F. Arnoldus and T. F. George, "Surface-Enhanced Correlations Between Polarized Photons in Resonance Fluorescence," *J. Phys. B* 21, 431-46 (1988).
58. D. A. Jelski and T. F. George, "Clusters: Link Between Molecules and Solids," *J. Chem. Ed.* 65, 879-83 (1988).
59. H. F. Arnoldus and T. F. George, "Memory Effects on Infrared Adsorbate Spectra," in Advances in Laser Sciences - III, ed. by A. C. Tam, J. L. Gole and W. C. Stwalley, AIP Conf. Proc. 172, 445-7 (1988).
60. D. Sahu and T. F. George, "Theory of the Tetragonal-to-Orthorhombic Structural Phase Transition in La_2CuO_4 ," *Solid State Commun.* 65, 1371-3 (1988).
61. S. G. Chung and T. F. George, "Generalized Levinson's Theorem and Quantum Sticking Coefficient at 0 K," *J. Phys. Soc. Jpn. (Letters)* 57, 20-3 (1988).
62. Z. C. Wu, D. A. Jelski and T. F. George, "Superconductors with Structured Surfaces: Fields and Currents," in Laser and Particle-Beam Chemical Processing for Microelectronics, ed. by D. J. Ehrlich, G. S. Higashi and M. M. Oprysko, Mat. Res. Soc. Symp. Proc. 101, 267-72 (1988).
63. Y. S. Kim, F. Battaglia and T. F. George, "Anomalies in the Heat-Capacity Signatures of Submonolayers Adsorbates with Attractive Lateral Interactions," *J. Chem. Phys.* 88, 7066-70 (1988).
64. H. F. Arnoldus and T. F. George, "Line Shape of an Atom-Crystal Bond," *Phys. Rev. B* 38, 978-86 (1988).
65. D. A. Jelski, P. T. Leung and T. F. George, "Photochemistry at Structured Surfaces: A Classical Electromagnetic Approach," *Int. Rev. Phys. Chem.* 7, 179-207 (1988).
66. H. F. Arnoldus and T. F. George, "Memory-Induced Extra Resonances of Adsorbates," *Phys. Rev. Lett.* 60, 1487-9 (1988).
67. A. Langner, D. Sahu and T. F. George, "Coupled Even-Parity Superconducting States: Square Lattice," in Superconductivity and Its Applications, ed. by H. S. Kwok and D. T. Shaw (Elsevier, New York, 1988), pp. 57-62.

68. I. Last and T. F. George, "Electronic States of the Xe HCl Systems in Gas and Condensed Phases," J. Chem. Phys. 89, 3071-8 (1988).ⁿ
69. P. T. Leung, Y. S. Kim and T. F. George, "Radiative Decay Rates for Molecules Near a Dielectric Sphere," J. Phys. Chem. 92, 6206-8 (1988).
70. D. Sahu, A. Langner and T. F. George, "Coupled Even-Parity Superconducting States," Phys. Rev. B 38, 2466-71 (1988).
71. C. I. Um, C. W. Jun, W. H. Kahng and T. F. George, "Coefficient of First Viscosity via Three-Phonon Processes in Bulk Liquid Helium," Phys. Rev. B 38, 8834-7 (1988).
72. A. Langner, D. Sahu and T. F. George, "Analysis of Thermodynamic and Transport Properties of $\text{La}_{2-x}\text{M}_x\text{CuO}_4$ and $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Superconductors," in Chemistry of High-Temperature Superconductors II, ed. by D. L. Nelson and T. F. George (American Chemical Society, Washington, D.C.), ACS Symp. Ser. 377, 18-25 (1988).
73. H. F. Arnoldus and T. F. George, "Light Scattering By a Phase Conjugator in the Four-Wave Mixing Configuration," J. Mod. Opt. 36, 31-51 (1989).
74. A. Langner, D. Sahu and T. F. George, "Coupled s-Wave and d-Wave States in the Heavy-Fermion Superconductor $\text{U}_{1-x}\text{Th}_x\text{Be}_{13}$," Phys. Rev. B 38, 9187-90 (1988).
75. D. Sahu, A. Langner, T. F. George, J. H. Weaver, H. M. Meyer III, D. L. Nelson and A. Wold, "Overview of High-Temperature Superconductivity: Theory, Surfaces, Interfaces and Bulk Systems," in Chemistry of High-Temperature Superconductors II, ed. by D. L. Nelson and T. F. George (American Chemical Society, Washington, D.C.), ACS Symp. Ser. 377, 1-15 (1988).
76. H. F. Arnoldus and T. F. George, "Symmetries of Spontaneous Decay for Atoms Near Any Surface," Surf. Sci. 205, 617-36 (1988).
77. C. I. Um, C. W. Jun, W. H. Kahng and T. F. George, "Thermal Conductivity and Viscosity via Phonon-Phonon, Phonon-Roton and Roton-Roton Scatterings in Thin ^4He Films," Phys. Rev. B 38, 8838-49 (1988).
78. D. A. Jelski, Z. C. Wu and T. F. George, "Large Silicon Clusters: Confirmation of Phillips' Conjecture," Chem. Phys. Lett. 150, 447-51 (1988).
79. P. T. Leung, Y. S. Kim and T. F. George, "Roughness-Induced Resonance for Molecular Fluorescence Near a Corrugated Metallic Surface," Phys. Rev. B 38, 10032-4 (1988).
80. Z. C. Wu, D. A. Jelski and T. F. George, "Critical Field Nucleation at the Structured Surface of a Superconductor," Z. Phys. B 73, 357-61 (1988).
81. A. Haque and T. F. George, "Dynamics of Observed Reality: Abridged Version of Classical and Quantum Mechanics," in Condensed Matter Theories, Vol. 4, ed. by J. Keller (Plenum, New York, 1989), pp. 223-36.

82. Y. S. Kim, P. T. Leung and T. F. George, "Remark on the Morphology-Dependent Resonance in the Decay Rate Spectrum for Molecules Near a Spherical Surface," *Chem. Phys. Lett.* 152, 453-6 (1988).
83. K. H. Yeon, C. I. Um, W. H. Kahng and T. F. George, "Propagators for Driven Coupled Harmonic Oscillators," *Phys. Rev. A* 38, 6224-30 (1988).
84. P. T. Leung and T. F. George, "Molecular Spectroscopy at Corrugated Metal Surfaces," *Spectroscopy* 4, 35-41 (1989).
85. H. F. Arnoldus and T. F. George, "Fresnel Coefficients for a Phase Conjugator," *J. Opt. Soc. Am. B* 6, 30-5 (1989).
86. H. R. Lee, H. G. Oh, T. F. George and C. I. Um, "Effect of Finite Size on Magnetoresistance," *Phys. Rev. B* 39, 2822-5 (1989).
87. K.-S. Lam and T. F. George, "Nonlocal and Quasilocal Potentials in the Spontaneous Emission of Molecular Exciplexes Coupled to the Phonon Bath of a Solid Matrix," *J. Chem. Phys.* 90, 1048-60 (1989).
88. C. I. Um, W. H. Kahng, M. H. Whang, S. K. Hong, H. G. Oh and T. F. George, "Sounds in One-Dimensional Superfluid Helium," *Phys. Rev. B* 39, 6537-43 (1989).
89. P. T. Leung, Y. S. Kim and T. F. George, "Photochemistry at Corrugated Thin Metal Films: A Phenomenological Approach," in Photochemistry in Thin Films, ed. by T. F. George, *Proc. Soc. Photo-Opt. Instrum. Eng.* 1056, 139-46 (1989).
90. L. Nanai, I. Hevesi, F. V. Bunkin, B. S. Luk'yanchuk, M. R. Brook, G. A. Shafeev, D. A. Jelski, Z. C. Wu and T. F. George, "Laser-Induced Metal Deposition on Semiconductors From Liquid Electrolytes," *Appl. Phys. Lett.* 54, 736-8 (1989).
91. P. T. Leung, Y. S. Kim and T. F. George, "Decay of Molecules at Corrugated Thin Metal Films," *Phys. Rev. B* 39, 9888-93 (1989).
92. P. T. Leung, Y. S. Kim and T. F. George, "Photoabsorption of Molecules at Corrugated Thin Metal Films," *J. Chem. Phys.* 90, 7472-7 (1989).
93. H. G. Oh, H. R. Lee, T. F. George and C. I. Um, "Exact Wave Functions and Coherent States of a Damped Driven Harmonic Oscillator," *Phys. Rev. A* 39, 5515-22 (1989).
94. H. G. Oh, H. R. Lee, T. F. George, C. I. Um, Y. M. Choi and W. H. Kahng, "Quantum Mechanics of a Molecular System Adsorbed on a Dielectric Surface," *Phys. Rev. A* 40, 45-53 (1989).
95. H. F. Arnoldus and T. F. George, "Interference Phenomena in Atomic Emission Near an Interface: Pure Classical Effects in Quantum Radiation," in Lasers and Applications, ed. by A. K. Popov (Krasnoyarsk Institute of Physics, USSR Academy of Sciences, Krasnoyarsk, USSR), in press.
96. X. Li, T. F. George and D. L. Lin, "Light Scattering from an Atom Near the Surface of a Superlattice," in Atomic and Molecular Physics, ed. by M. S. Z. Chaghtai (Aligarh Muslim University, Aligarh, India), in press.

97. X. S. Li, D. L. Lin, T. F. George and Z. D. Liu, "Nonresonant Interaction of a Three-Level Atom with Cavity Fields. IV. Atomic Dipole Moment and Squeezing Effects," *Phys. Rev. A* 40, 228-36 (1989).
98. Z. C. Wu, D. A. Jelski, T. F. George, L. Nanai, I. Hevesi, F. V. Bunkin, B. S. Luk'yanchuk, M. R. Brook and G. A. Shafeev, "Model of Laser-Induced Deposition on Semiconductors From Liquid Electrolytes," *Chem. Mater.* 1, 353-6 (1989).
99. F. Li, D. L. Lin, T. F. George and X. Li, "Dynamics of an M-Level Atom Interacting with Cavity Fields: Effects of the Level Number on Quantum Collapse and Revival," *Phys. Rev. A* 40, 1394-1401 (1989).
100. W. Trzeciakowski, D. Sahu and T. F. George, "Density of States in a Resonant Tunneling Structure," *Phys. Rev. B* 40, 6058-62 (1989).
101. H. R. Lee, H. G. Oh, T. F. George and C. I. Um, "Electronic Energy Levels in a Quantum Well Within an In-Plane Magnetic Field," *J. Appl. Phys.* 66, 2442-5 (1989).
102. P. C. Das, A. Puri and T. F. George, "Electromagnetic Reaction to Molecular Relaxation and Its Effect on Absorption Near a Rough Surface," *Solid State Commun.*, in press.
103. H. F. Arnoldus and T. F. George, "Extraordinary Behavior of Atoms Near a Phase Conjugator," in *Coherence and Quantum Optics VI*, ed. by L. Mandel and E. Wolf (Plenum Press, New York, 1989), in press.
104. X. Li, D. L. Lin and T. F. George, "Squeezing of Atomic Variables in the One- and Two-Photon Jaynes-Cummings Model," *Phys. Rev. A* 40, 2504-7 (1989).
105. F. Li, X. Li, D. L. Lin and T. F. George, "Squeezing of Cavity Fields in Cascade Multiphoton Processes," *J. Phys. B: At. Mol. Opt. Phys.* 22, 2977-83 (1989).
106. L. N. Pandey, D. Sahu and T. F. George, "Dwell Time and Average Local Speed in a Resonant Tunneling Structure," *Solid State Commun.* 72, 7-11 (1989).
107. C. I. Um, C. W. Jun, H. Joon Shin and T. F. George, "Quasi-Diffusion between Phonon and Roton Gases in Two- and Three-Dimensional Liquid Helium," *J. Low-Temp. Phys.*, in press.
108. F. Li, X. Li, D. L. Lin and T. F. George, "Dynamics of an M-Level Atom Interacting with Cavity Fields. II. Properties of Photon Statistics," *Phys. Rev. A* 40, 5129-34 (1989).
109. X. Sun, D. Lu, R. Fu, D. L. Lin and T. F. George, "Gap States of Charged Solitons in Polyacetylene," *Phys. Rev. B*, in press.
110. C. I. Um, W. H. Kahng, E. S. Yim and T. F. George, "Ground State of a Two-Dimensional Charged-Boson System," *Phys. Rev. B*, in press.
111. X. Li, D. L. Lin, T. F. George and X. Sun, "Optical Nutation in Polymers Irradiated by Ultrashort Laser Pulses," *Phys. Rev. B*, in press.

112. H. R. Lee and T. F. George, "Local Pairing and Antiferromagnetism in High-T_c Superconductors," in Superconductivity and Applications, ed. by H. S. Kwok, Y. H. Kao and D. T. Shaw (Plenum, New York, 1989), in press.
113. D. L. Lin, R. Chen and T. F. George, "Interface Phonons in Semiconductor Double Heterostructures," *Solid State Commun.*, in press.
114. R. Chen, D. L. Lin and T. F. George, "Optical Phonon Modes in a Double Heterostructure of Polar Crystals," *Phys. Rev. B*, in press.
115. H. F. Arnoldus and T. F. George, "Observation of Atomic Relaxation Near an Interface Through Detection of Emitted Fluorescence," *Com. At. Mol. Phys.*, in press.
116. D. A. Jelski, Z. C. Wu and T. F. George, "An Inquiry Into the Structure of the Si₆₀ Cluster: Analysis of Fragmentation Data," *J. Cluster Sci.*, in press.
117. L. N. Pandey, D. Sahu and T. F. George, "Density of Electronic States in a Biased Resonant Tunneling Structure," *Appl. Phys. Lett.*, in press.
118. X. Sun, C. Wu, R. Fu, D. L. Lin and T. F. George, "Strongly Coupled One-Dimensional System and the Polymer," *Proceedings of the Yamada Conference on Strongly Coupled Plasma Physics*, ed. by S. Ichimaru (Tokyo, Japan, 1989), in press.
119. F. Li, X. Li, D. L. Lin and T. F. George, "Squeezing of Many-Atom Radiation in an Optical Cavity," *Phys. Rev. A*, in press.

Conference Abstracts

1. K. S. Lam and T. F. George, "Cooperative Laser/Collision-Induced Chemical Bonds," Abstracts of the Workshop on Photons and Continuum States of Atoms and Molecules (Cortona, Italy, 1986), p. 11.
2. T. F. George, "Chemical Dynamics," Abstracts of the Workshop on Lasers, Molecules and Methods (Los Alamos National Laboratory, Los Alamos, New Mexico, 1986).
3. T. F. George, "Laser-Stimulated Processes at Metallic Microstructures and Surfaces," in Proceedings of the Contact Groups, Vol. 1 (Fonds National de la Recherche Scientifique, Brussels, Belgium, 1986), pp. 67-9.
4. A. Peremans, J. Darville, J.-M. Gilles and T. F. George, "Infrared-Laser Excitation of the Internal Vibrational Mode of a Diatomic Molecule Adsorbed on a Metal Surface," in Proceedings of the Contact Groups, Vol. 1 (Fonds National de la Recherche Scientifique, Brussels, Belgium, 1986), p. 72.
5. T. F. George, "Recent Advances in the Theory of Laser-Induced Chemistry at Gas-Solid Interfaces," Abstracts of the International Conference on Chemistry by Infrared Lasers (Liblice, Czechoslovakia, 1986).
6. J. T. Lin, X. Y. Huang and T. F. George, "Thermally-Induced Phase Conjugation and Lifetime Variation of a Dipole in a Phase-Conjugation Cavity," Technical Digest of the International Conference on Lasers '86 (Orlando, Florida, 1986), Paper No. WC.5.
7. S. van Smaalen and T. F. George, "Theory of an Infrared Irradiated Adbond," Bull. Am. Phys. Soc. 32, 302 (1987) [also in Optics News 12, 199 (1986)].
8. T. F. George, "Theory of Periodic Growth in Laser-Induced Chemical Vapor Deposition," Bull. Am. Phys. Soc. 32, 674 (1987).
9. S. G. Chung and T. F. George, "Quantum Adsorption in the Low-Energy Limit," Bull. Am. Phys. Soc. 32, 910 (1987).
10. A. Peremans, J. Darville, J.-M. Gilles and T. F. George, "Infrared Laser-Stimulated Catalysis. Theory and Experimental Set-up for the Study of a Model System: Methanol on Pt-Rh Alloys," Abstracts of the 9th European Conference on Surface Science (Luzern, Switzerland, 1987), No. Pb-062.
11. A. Peremans, J. Darville, J.-M. Gilles and T. F. George, "Infrared-Laser Excitation of a Diatomic Molecule Adsorbed on a Metal Surface," Abstracts of the General Scientific Meeting of the Belgian Society of Physics (University of Limburgs, Belgium, 1987), No. CM43.
12. A. Haque and T. F. George, "Semiclassical Dynamics in Three-Dimensional Phase-Space," Abstracts of the 11th International Workshop on Condensed Matter Theories (Oulu, Finland, 1987), p. 23.
13. T. F. George, "Theory of Laser-Induced Processes in Molecules," Abstracts of the Conference on Laser-Induced Processes in Matter (Helsinki, Finland, 1987), No. VII.1.

14. H. F. Arnoldus and T. F. George, "Line Shapes of Adsorbed Atoms on a Crystal," *Bull. Am. Phys. Soc.* 32, 1629 (1987).
15. D. A. Jelski, Z. C. Wu and T. F. George, "Laser-Induced Chemistry Above a Superconducting Surface," *Final Program and Abstracts of the Materials Research Society 1987 Fall Meeting (Boston, Massachusetts, 1987)*, p. 114.
16. A. Haque and T. F. George, "On the Use of Gaussian Wavepacket Dynamics in Determining Electronic Spectra of Br_2 in an Ar Matrix," *Abstracts of the XIIth International Workshop on Condensed Matter Theories (Taxco, Mexico, 1988)*.
17. D. Sahu, A. Langner and T. F. George, "Magnetic and Electronic Properties of Coupled Superconducting States," *Abstracts of Papers of the 196th American Chemical Society National Meeting (Los Angeles, California, 1988)*, Div. Phys. Chem. No. 5.
18. T. F. George, "Research Program in Tom George's Group," *Abstracts of the VIIth National Workshop and Conference on Atomic and Molecular Physics (Aligarh, India, 1988)*, pp. 148-50.
19. X. Xia, A. Langner and T. F. George, "Geometry and Binding Energy of the C H_{n+2} -X Charge-Transfer Complex," *Seventh Annual Chemistry Graduate Students' Symposium (State University of New York, Buffalo, New York, 1989)*, No. 87.
20. H. F. Arnoldus and T. F. George, "Extraordinary Behavior of Atoms Near a Phase Conjugator," *Abstracts of the Sixth Rochester Conference on Coherence and Quantum Optics (Rochester, New York, 1989)*, pp. 30-2.
21. D. Sahu, A. Langner, L. N. Pandey, W. Trzeciakowski and T. F. George, "Electron Transfer in Multiple Quantum-Well Structures: Resonant Tunneling Diodes and Conjugated Polymers," *Abstracts of Papers of the 198th American Chemical Society National Meeting (Miami, Florida, 1989)*, Div. Phys. Chem. No. 46.
22. D. A. Jelski and T. F. George, "Structure and Properties of Large Silicon Clusters," *Abstracts of Papers of the 198th American Chemical Society National Meeting (Miami, Florida, 1989)*, Div. Phys. Chem. No. 62.
23. A. Haque and T. F. George, "Phase-Space Dynamical Simulation of the Low-Temperature Properties of Liquid ^4He ," *Abstracts of the VIth International Conference on Recent Progress in Many-Body Theories (Arad, Israel, 1989)*, p. A-12.
24. D. L. Lin, X. Li and T. F. George, "Theoretical Investigation of Optical Responses in Polymers," *Abstracts of the Air Force Office of Scientific Research Surface Chemistry Contractors Conference (Captiva Island, Florida, 1989)*, p. 45.